THE UNIVERSITY OF TENNESSEE

DEPARTMENT OF ELECTRICAL ENGINEERING

DEVELOPMENT

OF A

FREQUENCY STEERABLE ANTENNA

INTERIM DEVELOPMENT REPORT NO. 19

10 April 1954

Navy Department Bureau of Ships
Electronics Divisions
Contract No. NObsr-57448 Index No. NE-091035 ST7

A PROJECT OF THE ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE COLLEGE OF ENGINEERING
Knoxville, Tennessee

INTERIM DEVELOPMENT REPORT

FOR

DEVELOPMENT OF A HIGH FREQUENCY

STEERABLE ANTENNA

This report covers the period
1 March 1954 to 31 March 1954

ENGINEERING EXPERIMENT STATION
THE UNIVERSITY OF TENNESSEE
KNOXVILLE, TENNESSEE

Navy Department | Bureau of Ships
Electronics Divisions

Contract No. NObsr-57448 | Index No. NE-091035 ST7

10 April 1954

Copy No. 10

ABSTRACT

This report covers work done on Contract No. Nobsr-57448, Index No. NE-091035 ST7, at The University of Tennessee during the month of March 1954.

The following was accomplished:

1. A vertically stacked end-fire array of rhombic antennas has been partially investigated as an additional method of obtaining vertical steering. Horizontal patterns of a simple vertically stacked array of rhombic antennas are being calculated.

2. Radiation patterns of the circular traveling wave antenna have been measured over a wide range of frequencies.

3. The vertical radiation pattern for the vertical half-rhombic antenna, over an imperfect earth, has been calculated for 10^{o} increments.

PART I.

Purpose

This project involves the development of a high frequency steerable antenna having the following characteristics:

1. It shall be operable throughout the frequency range of 4 to 32 megacycles per second.

2. It shall be capable of four, or more, simultaneous transmissions on different frequencies, and at different azimuth and elevation angles.

3. For each transmission, it shall be capable of being directed to any azimuth angle and to any elevation angle between the horizon and 30° above the horizon.

The communication system shall provide reliable 24-hour day-to-day communication with a 20-decibel signal-to-noise ratio. The ranges to be covered are from approximately 500 nautical miles to 4000 nautical miles.

The development consists of two phases:

Phase I. Theoretical and experimental studies.

Phase II. Development of design criteria.

General Factual Data

Personnel:

F. V. Schultz	Project Director	98	Man-hours
W. E. Lear	Associate Professor	40	Man-hours
W. O. Leffell	Assistant Professor	4	Man-hours
W. J. Bergman	Junior Engineer	184	Man-hours
H. P. Neff	Junior Engineer	184	Man-hours
Lillian W. Conner	Secretary	45-1/2	Man-hours
L. Phillips	Technician	24	Man-hours
F. Collins	Draftsman	9-1/2	Man-hours
K. Bell	Student Computer	10-1/2	Man-hours
G. Craig	Student Computer	6-1/2	Man-hours
D. Guhne	Student Computer	3	Man-hours
H. Knox	Student Computer	109	Man-hours
G. Rolfe	Student Computer	85	Man-hours
J. Roote	Student Computer	23-1/2	Man-hours
D. C. Rupley	Student Computer	4	Man-hours
G. C. Watkins	Student Computer	33	Man-hours
L. Zollinger	Student Computer	76-1/2	Man-hours

References

Bruce, E., Beck, A. C. and Lowry, L. R., "Horizontal Rhombic Antennas," Bell System Technical Journal, Vol. 14, pp. 135-138, January 1935.

Foster, Donald, "Radiation From Rhombic Antennas," Proceedings IRE, Vol. 25, pp. 1327-1353, October 1937.

Friis, H. T., and Feldman, C. B., "A Multiple Unit Steerable Antenna for Short-Wave Reception," Bell System Technical Journal, Vol. 16, pp. 337-419, July 1937.

Harper, A. E., Rhombic Antenna Design, D. Van Nostrand Co., Inc., New York, 1941.

Jahnke, Eugene and Emde, Fritz, Tables of Functions, Dover Publications, Inc., New York, 1945.

Kraus, J. D., Antennas, McGraw-Hill Book Co., New York and London, 1950.

McLachlan, N. W., Bessel Functions For Engineers, Clarendon Press, Oxford, 1934.

Pickard and Burns, Inc., "Theoretical and Experimental Studies of High Phase Velocity Antennas," Contract No. NObsr-63035, Index No. NE-091035, Subtask Number 4, Phase B, December 1953.

Relton, F. E., Applied Bessel Functions, Blackie and Son Limited, London and Glasgow, 1946.

Terman, F. E., Radio Engineers Handbook, McGraw-Hill Book Co., New York and London, 1943.

Watson, G. N., Theory of Bessel Functions, Cambridge University Press, Cambridge, 1922.

Detail Factual Data

1. In Interim Development Report No. 18 under Contract NObsr-57448 it was shown that an array of vertically stacked rhombics covers nearly all of the range of elevation angles required over a frequency range of four to one. Incomplete coverage is obtained only at lower elevation angles for the lower frequencies (determined from ionospheric studies). An attempt has been made to improve this array with respect to low angle radiation at the lower frequencies. An array of stacked rhombics in an end-fire array is presently being investigated as an additional means of obtaining vertical steering. (It is hoped that this array will cover all of the elevation angles required.)

Typical horizontal patterns for various elevation angles are shown in Figures 1 through 15 for the arrays of stacked rhombics investigated in Interim Development Report No. 18. These patterns are for E_ϕ, the perpendicularly, or horizontally polarized component of the electric field, only. At low elevation angles the E_θ component of the electric field is rather small and will be neglected temporarily. Horizontal beamwidths are of the order of 20° for these arrays, indicating that 9 or more of these arrays of stacked rhombics would be needed to cover 360° in azimuth if each array were made optionally unidirectional (that is, the termination end and the feed end interchangeable).

2. Radiation patterns of the circular traveling wave antenna model have been measured over a frequency range of 350-1200 Mc. The termination used for these patterns is a high-attenuation open-wire transmission line, constructed of 0.001-inch diameter nichrome wire, with a characteristic impedance designed to be 800 ohms.

The mathematical analysis of the circular traveling-wave antenna is being investigated in an attempt to simplify calculation of the theoretical patterns. The theoretical analysis produces integrals of the form

$$F_y = \int_0^{\pi} \cos\theta \, \epsilon^{-j(Z\theta - a\cos\theta - b\sin\theta)} \, d\theta$$

The first evaluation of this integral produced a group of terms containing products of Bessel functions and trigonometric functions in infinite summations, with the rapidity of convergence dependent on antenna dimensions, and for this reason, a simpler expression is being sought.

3. The vertical radiation pattern for the vertical half-rhombic antenna, over an imperfect earth, has been calculated for 10° increments. A plot of these values failed to satisfactorily locate the nodes, and additional calculations will be made at intermediate points in order to remedy this.

DEPARTMENT OF ELECTRICAL ENGINEERING - ENGINEERING EXPERIMENT STATION

THE UNIVERSITY OF TENNESSEE

PROJECT PERFORMANCE AND SCHEDULE

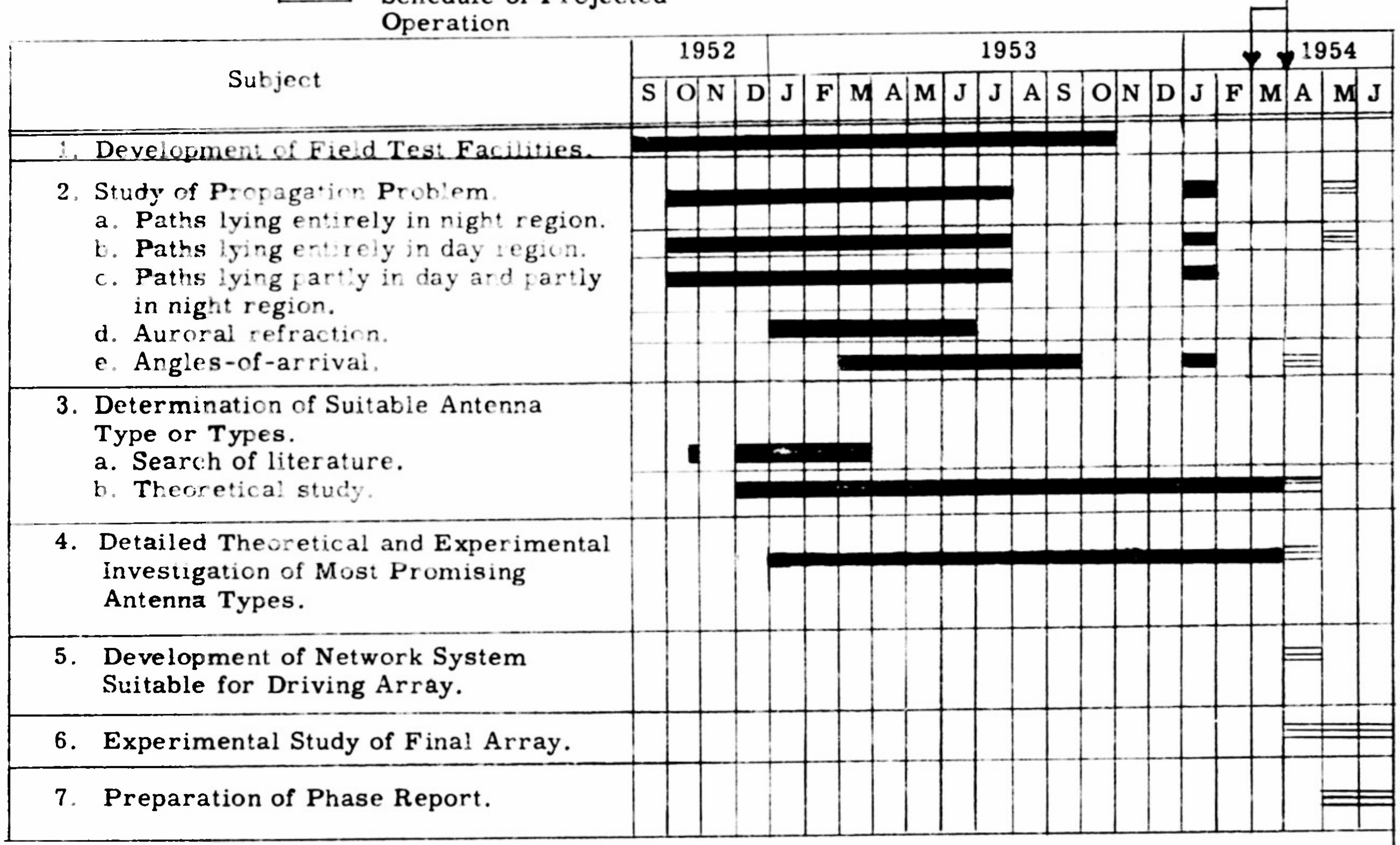
Index No. NE-091035 ST7

Date: 10 April 1954

Contract No. NObsr-57448

Period Covered: 1/3/54 to 31/3/54

Legend: Work Performed; Schedule of Projected Operation



Conclusions

1. The horizontal patterns of a stacked rhombic array show average beamwidths of the order of twenty degrees.

PART II

Program for Next Interval

1. An attempt will be made to improve the elevation angle and frequency coverage of the stacked rhombic array, especially at lower frequencies.

2. The investigation of the theoretical pattern of the circular traveling wave antenna will be continued.

3. Calculation of the vertical radiation pattern of the vertical half-rhombic antenna, over an imperfect earth, will be continued.

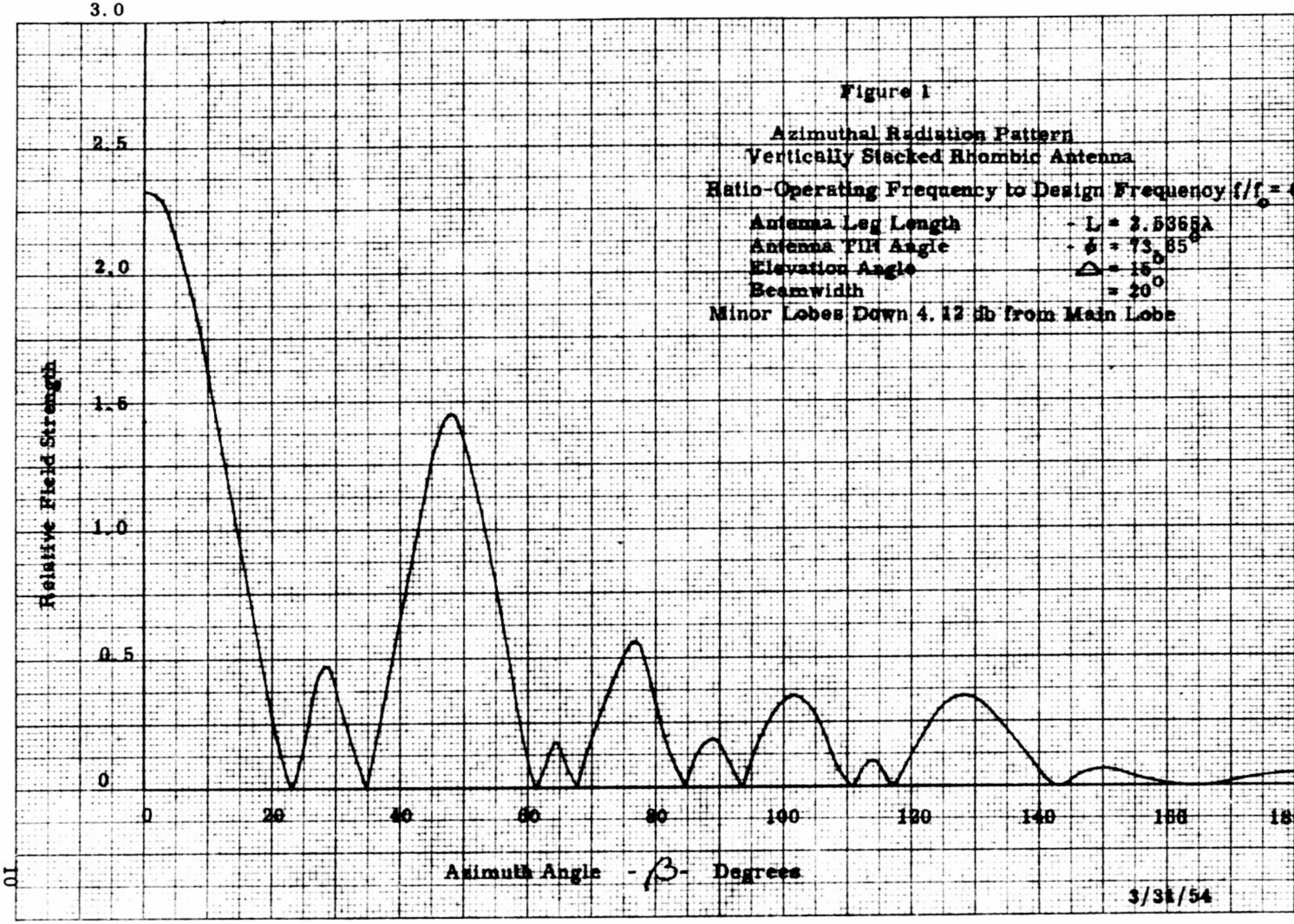


Figure 1

Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency $f/f_o = 0.5$

Antenna Leg Length	- $L = 2.5365\lambda$
Antenna Tilt Angle	- $\phi = 73.85^o$
Elevation Angle	$\Delta = 15^o$
Beamwidth	$= 20^o$

Minor Lobes Down 4.12 db from Main Lobe

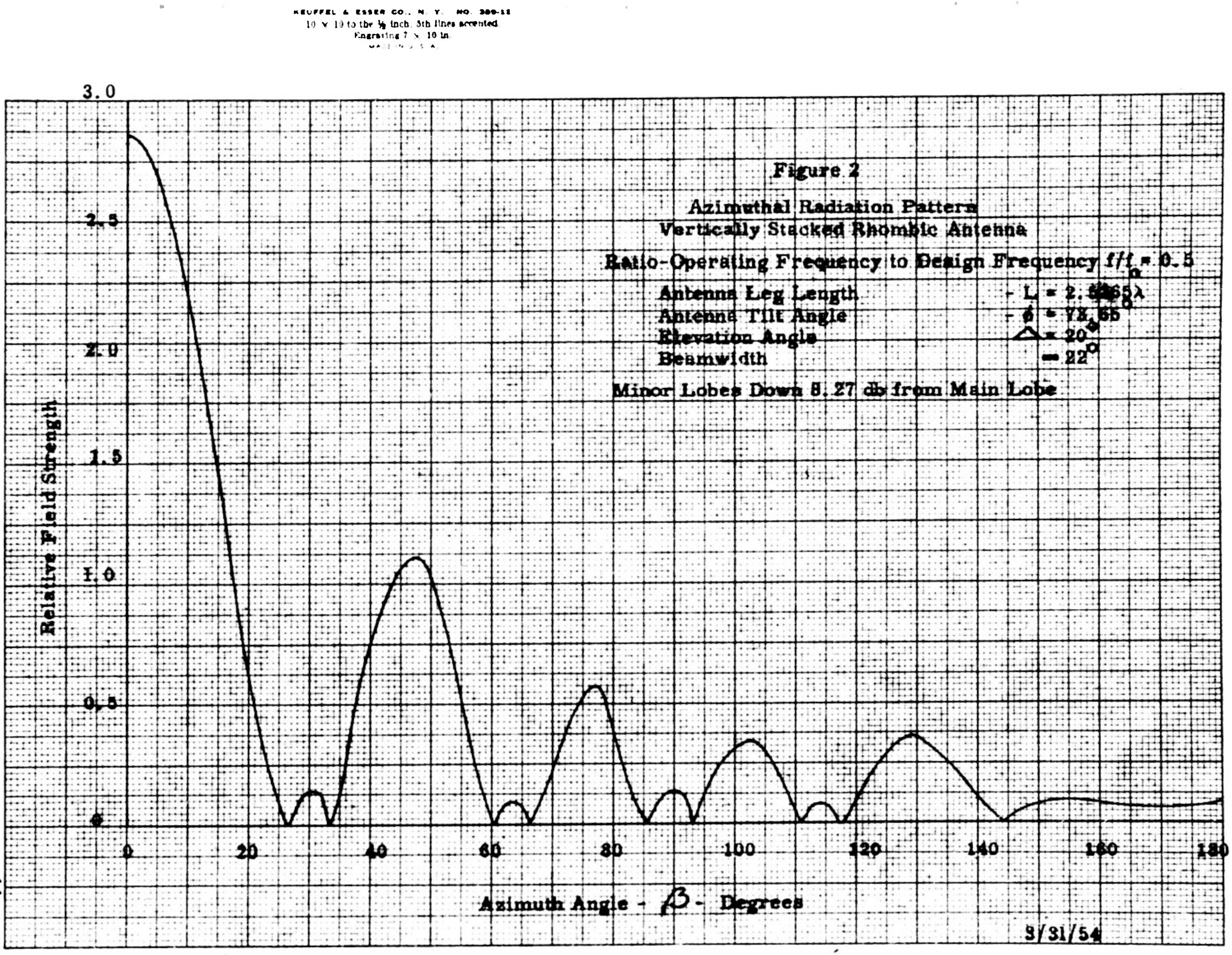


Figure 2

Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

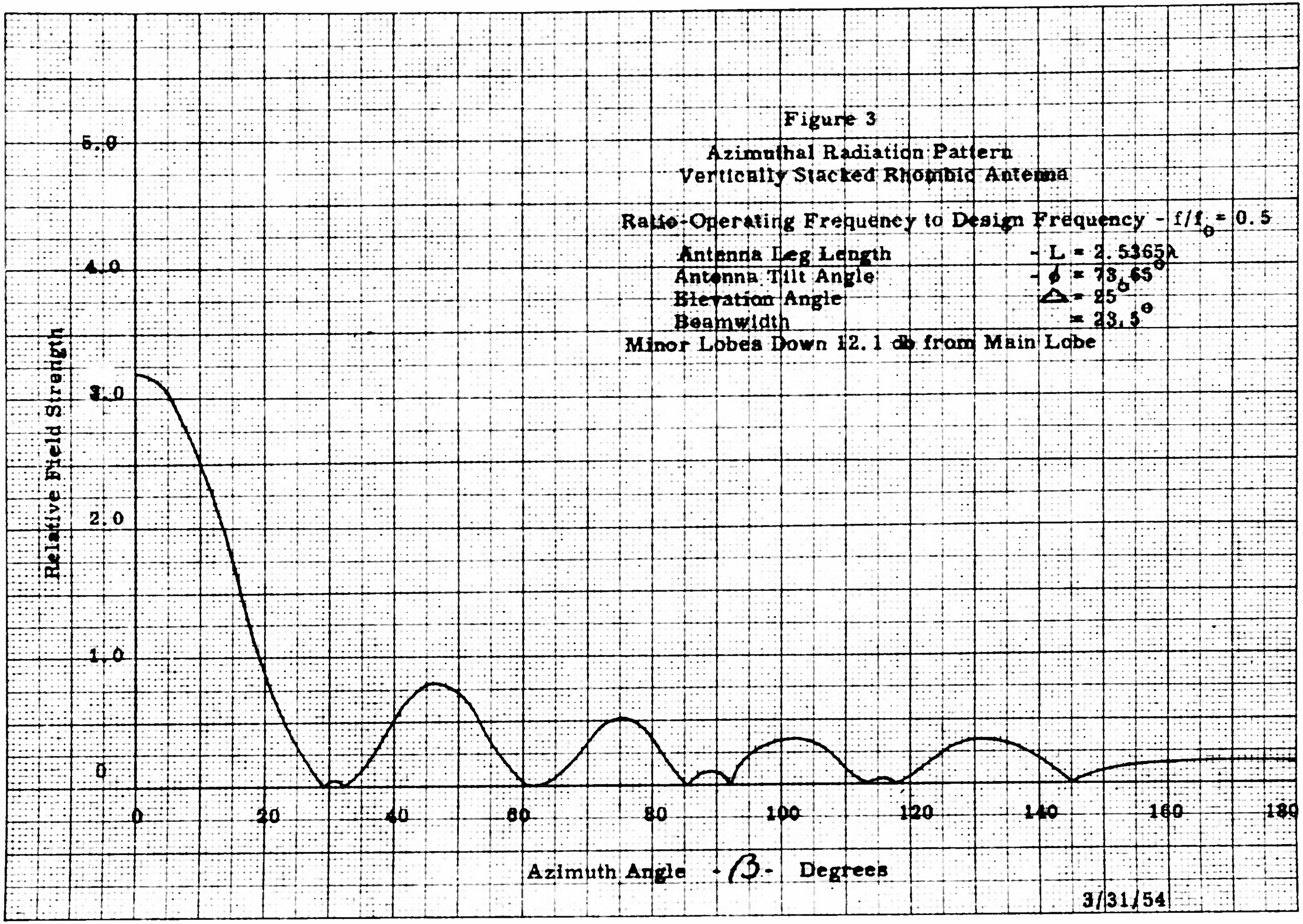


Figure 3

Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency - $f/f_o = 0.5$

Antenna Leg Length - $L = 2.5365\lambda$
Antenna Tilt Angle - $\phi = 73.65^\circ$
Elevation Angle $\Delta = 25^\circ$
Beamwidth $= 23.5^\circ$
Minor Lobes Down 12.1 db from Main Lobe

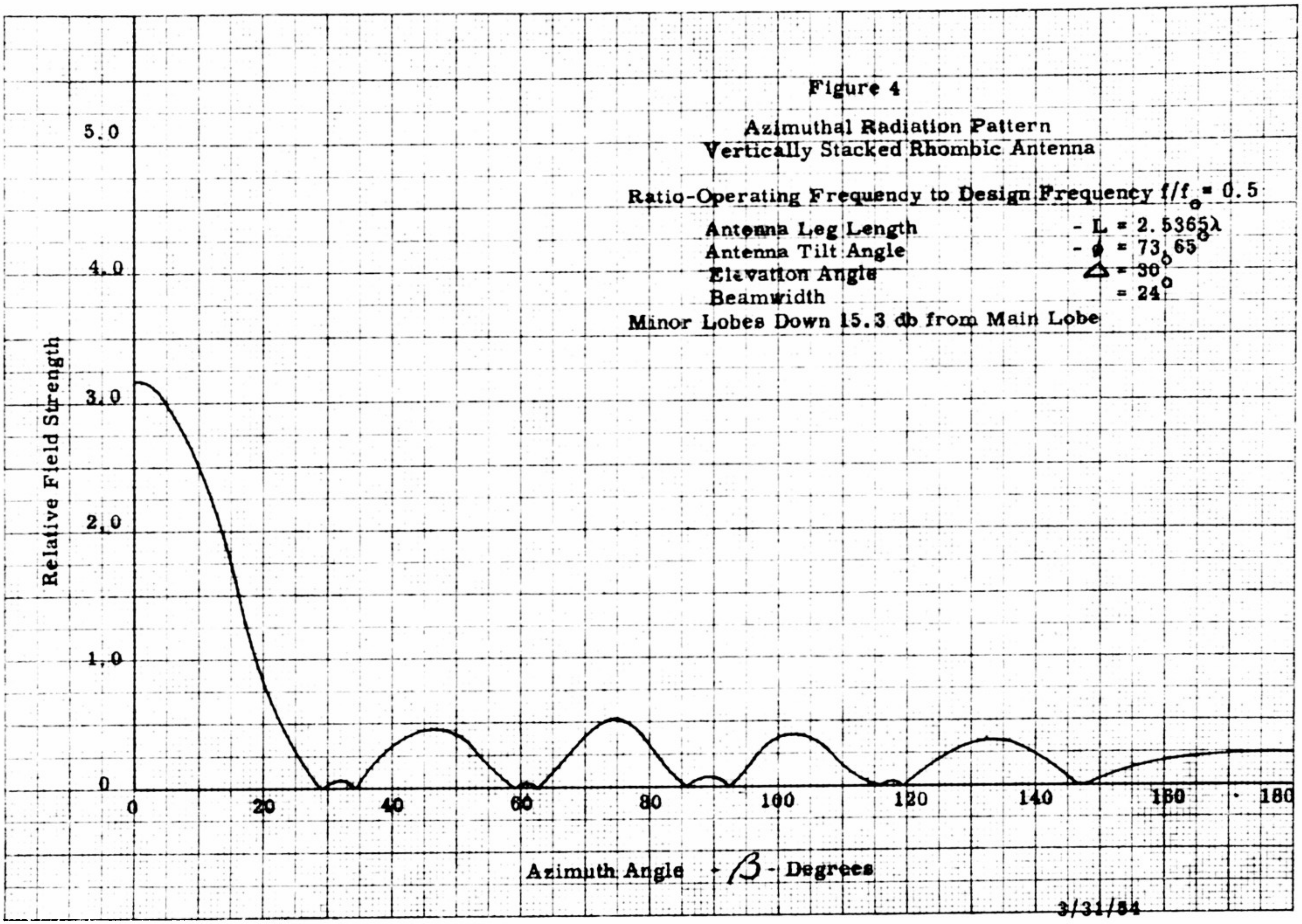


Figure 4

Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency $f/f_o = 0.5$

Antenna Leg Length	- $L = 2.5365\lambda$
Antenna Tilt Angle	- $\phi = 73.65^o$
Elevation Angle	$\Delta = 30^o$
Beamwidth	$= 24^o$

Minor Lobes Down 15.3 db from Main Lobe

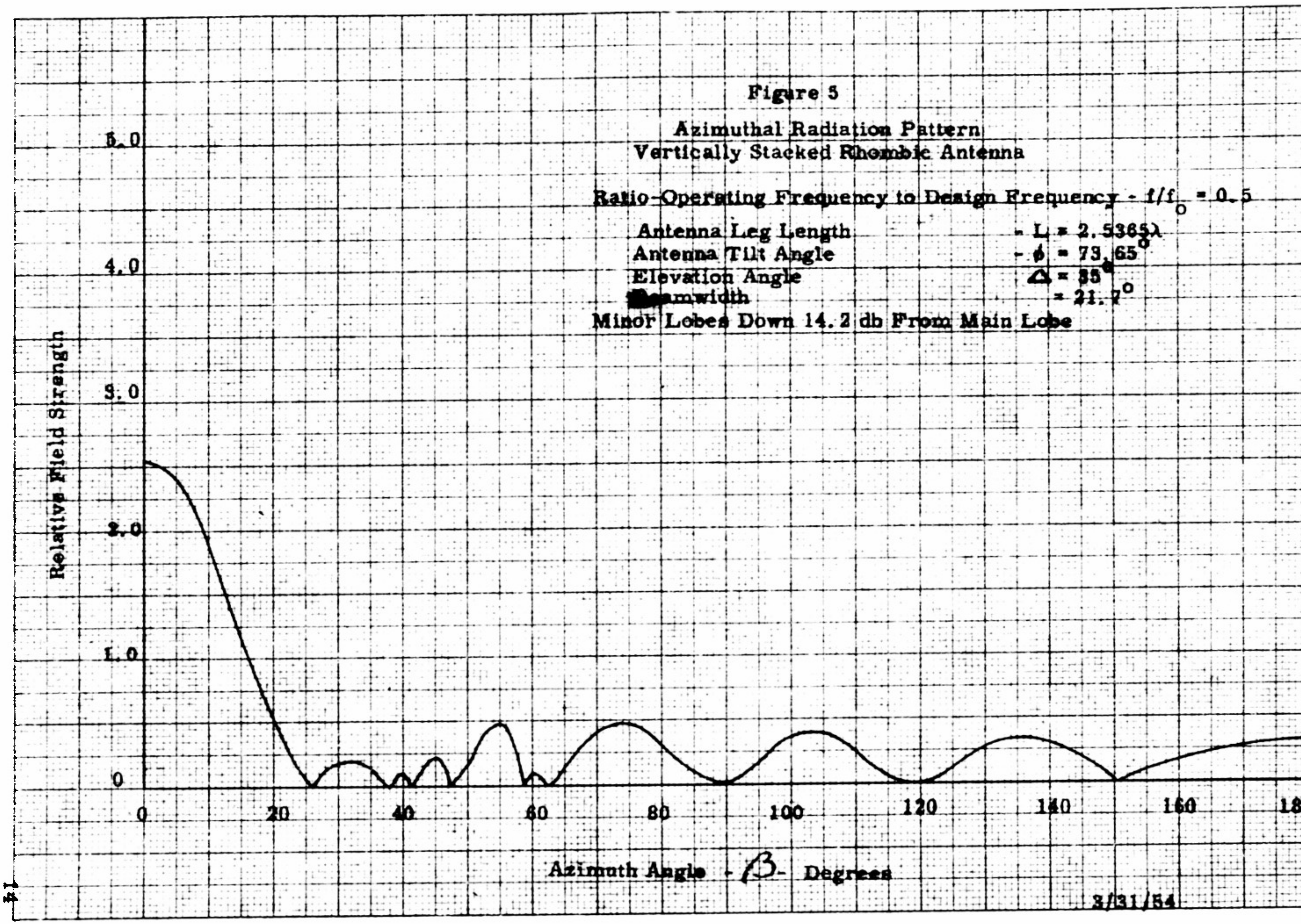


Figure 5
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna
Ratio-Operating Frequency to Design Frequency - f/f$_o$ = 0.5
Antenna Leg Length - L = 2.5365λ
Antenna Tilt Angle - ϕ = 73.65°
Elevation Angle Δ = 35°
Beamwidth = 21.7°
Minor Lobes Down 14.2 db From Main Lobe
Relative Field Strength
5.0
4.0
3.0
2.0
1.0
0
0
20
40
60
80
100
120
140
160
180
Azimuth Angle - β - Degrees
3/31/54

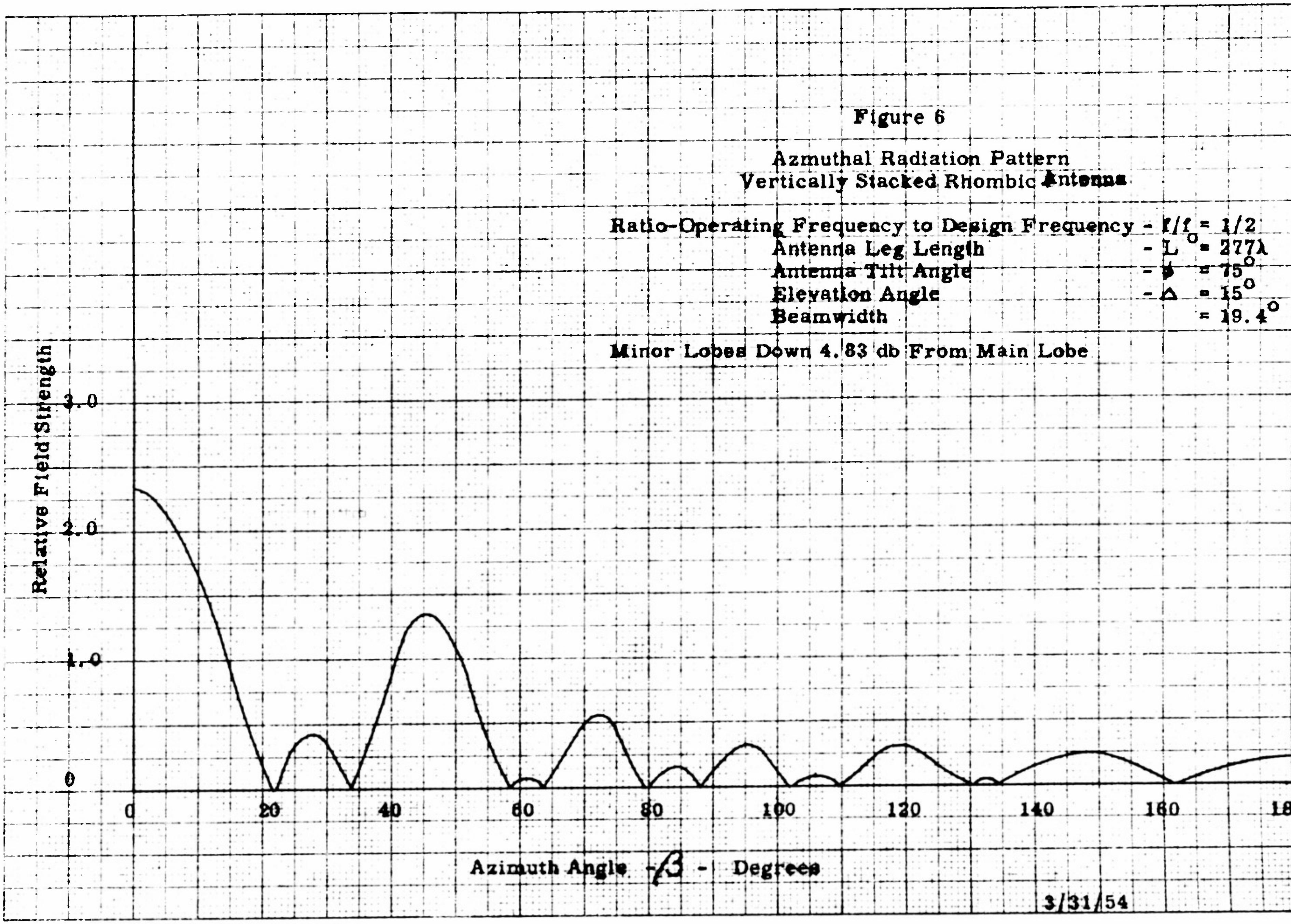


Figure 6

Azmuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

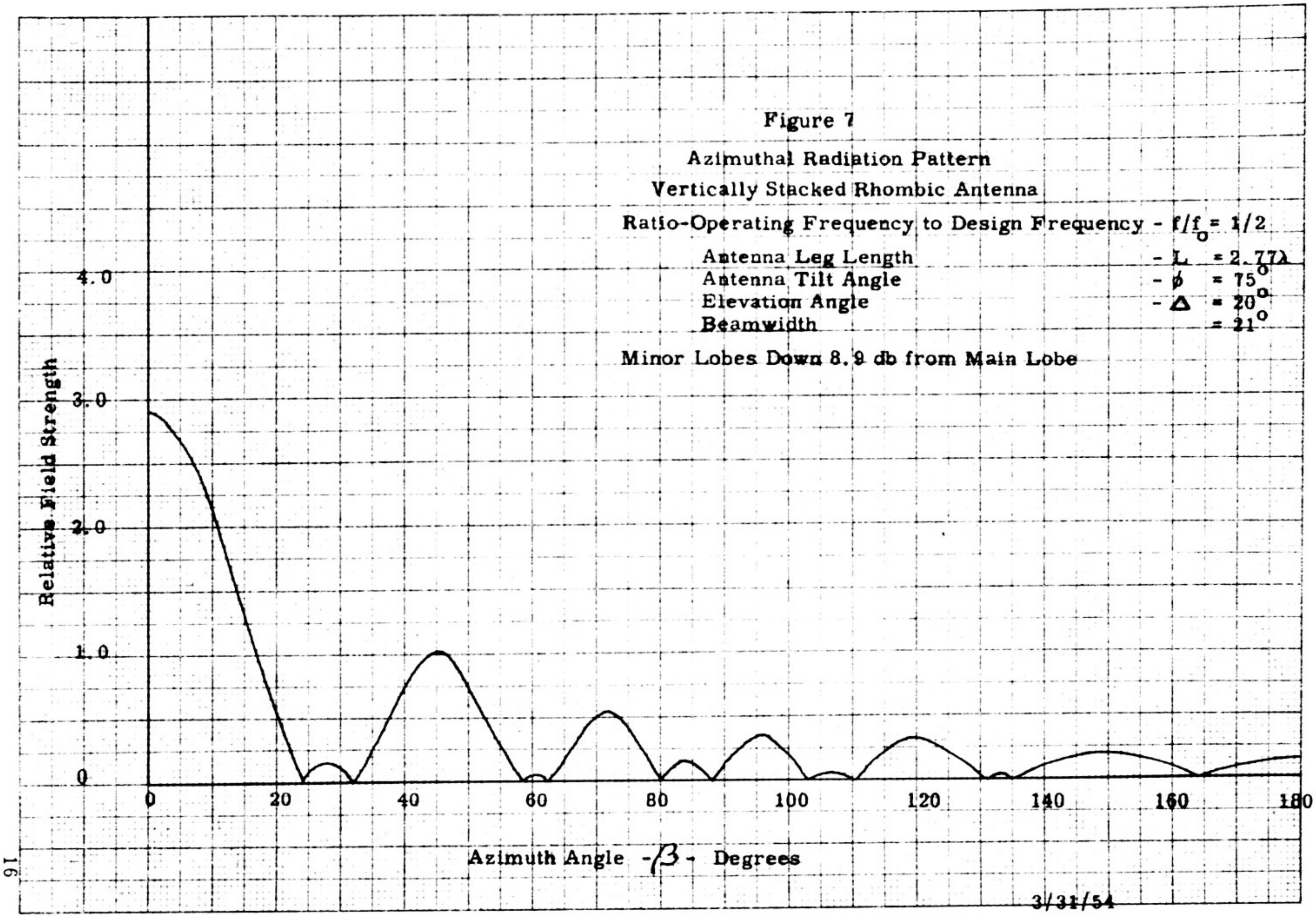


Figure 7
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna
Ratio-Operating Frequency to Design Frequency - $f/f_o = 1/2$
Antenna Leg Length - L = 2.77λ
Antenna Tilt Angle - ϕ = 75°
Elevation Angle - Δ = 20°
Beamwidth = 21°
Minor Lobes Down 8.9 db from Main Lobe
Relative Field Strength
0
1.0
2.0
3.0
4.0
0
20
40
60
80
100
120
140
160
180
Azimuth Angle - β - Degrees
3/31/54

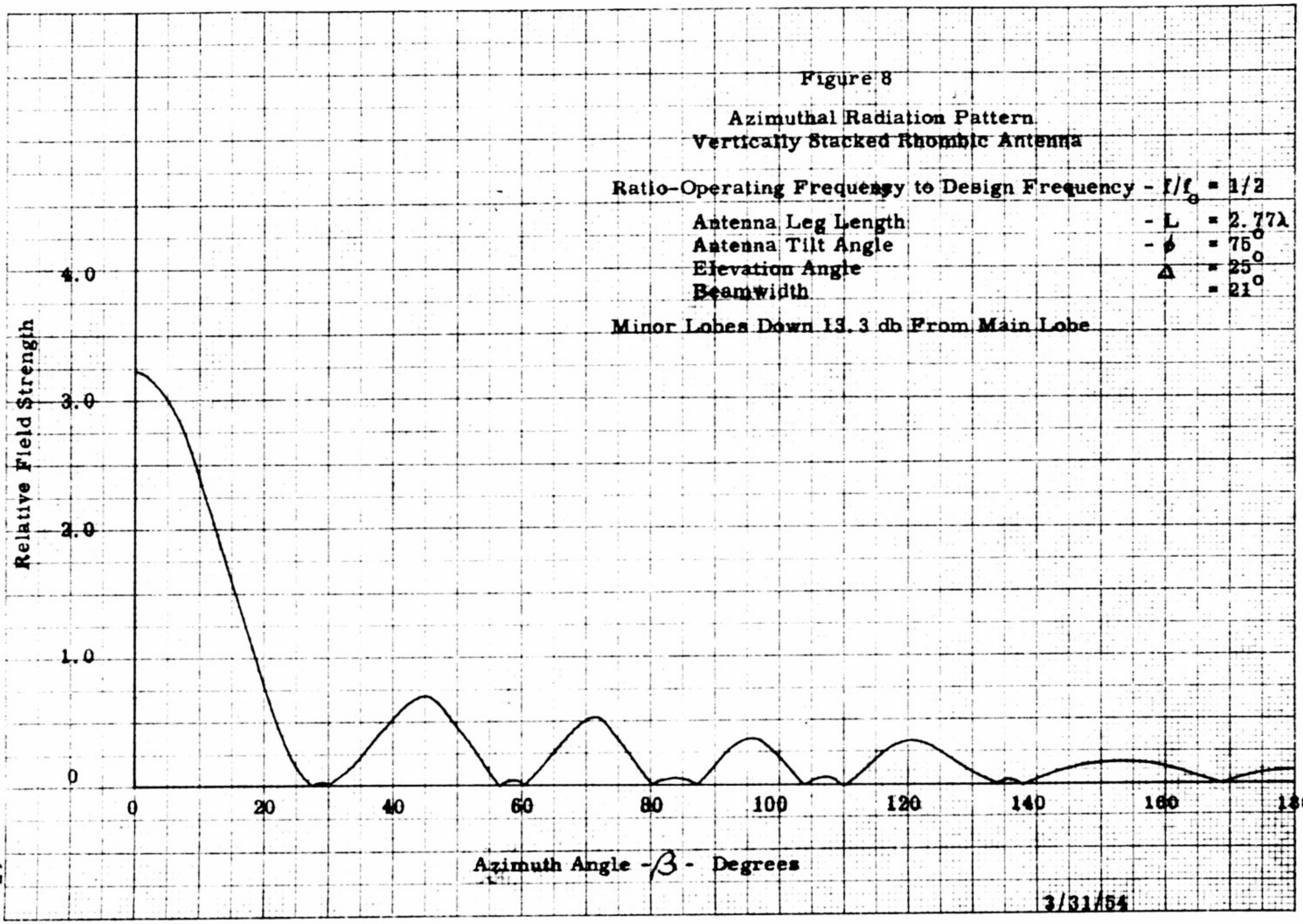


Figure 8
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna
Ratio-Operating Frequency to Design Frequency - f/f_o = 1/2
Antenna Leg Length - L = 2.77λ
Antenna Tilt Angle - ϕ = 75°
Elevation Angle Δ = 25°
Beamwidth = 21°
Minor Lobes Down 13.3 db From Main Lobe
Relative Field Strength
4.0
3.0
2.0
1.0
0
0
20
40
60
80
100
120
140
160
180
Azimuth Angle - β - Degrees
3/31/54

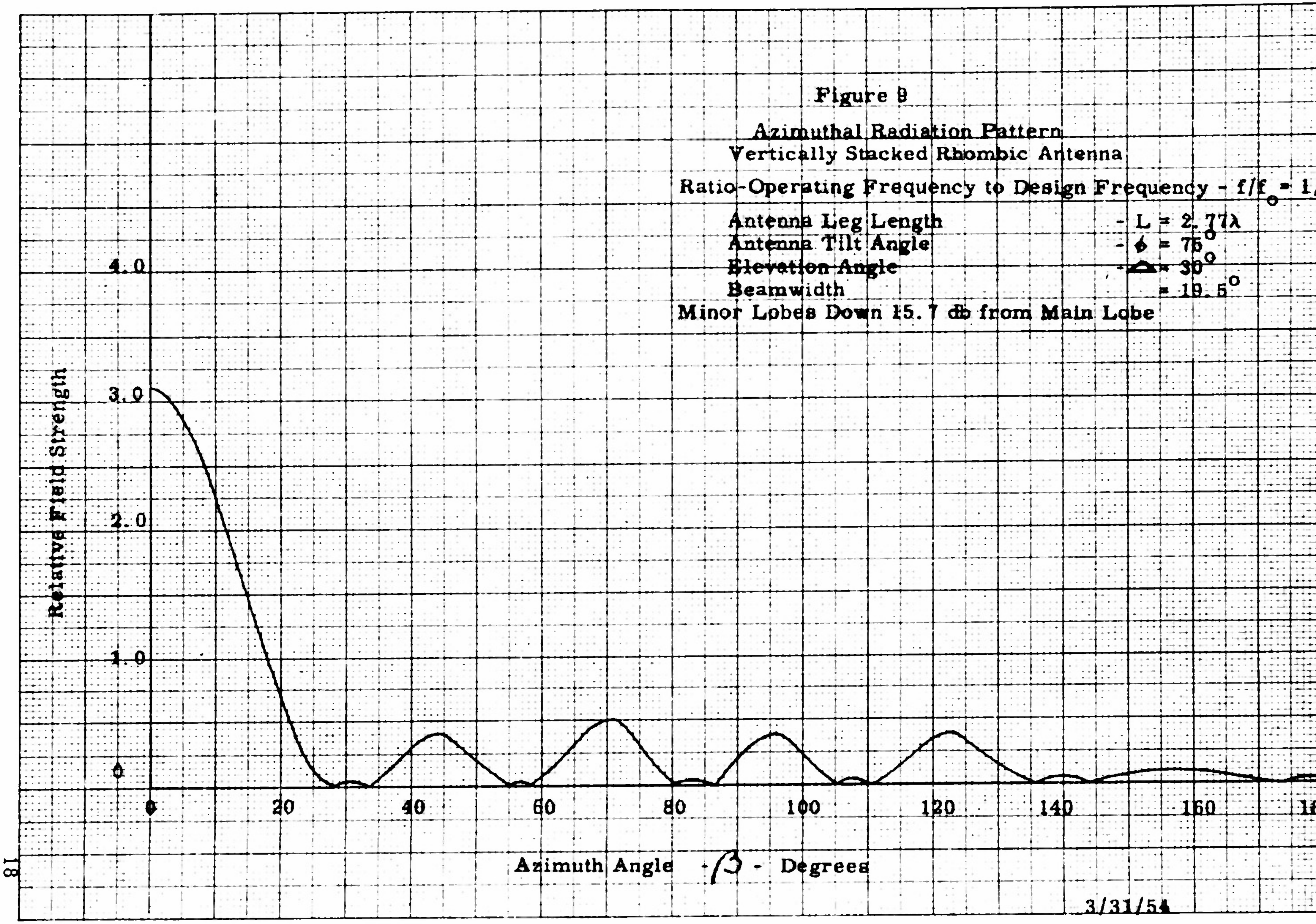


Figure 9

Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency - $f/f_o = 1/2$

Antenna Leg Length	- $L = 2.77\lambda$
Antenna Tilt Angle	- $\phi = 75^o$
Elevation Angle	- $\Delta = 30^o$
Beamwidth	$= 19.5^o$

Minor Lobes Down 15.7 db from Main Lobe

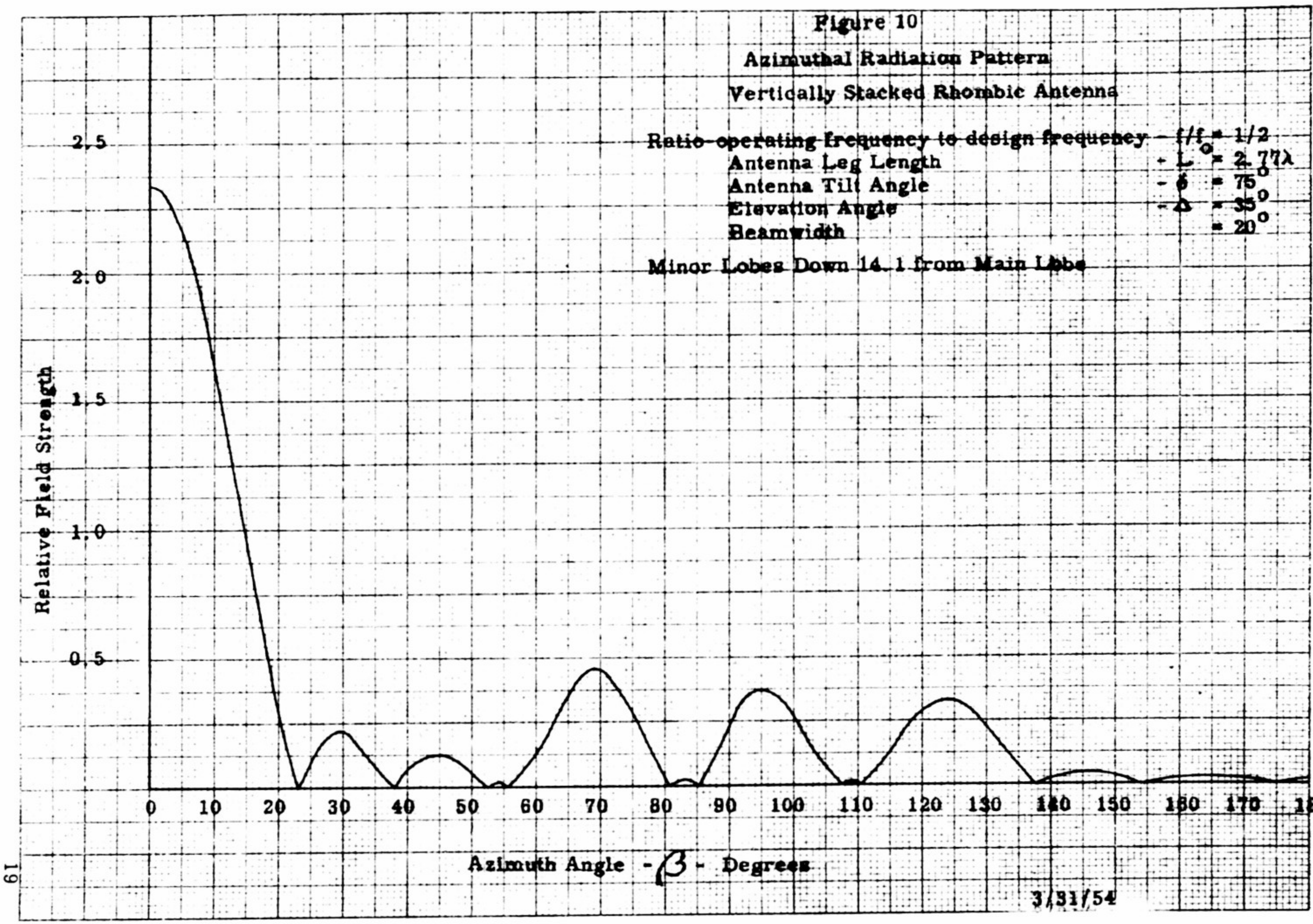


Figure 10
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna
Ratio operating frequency to design frequency - f/f_o = 1/2
Antenna Leg Length - L = 2.77λ
Antenna Tilt Angle - ϕ = 75°
Elevation Angle - Δ = 35°
Beamwidth = 20°
Minor Lobes Down 14.1 from Main Lobe
Relative Field Strength
2.5
2.0
1.5
1.0
0.5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Azimuth Angle - β - Degrees
3/31/54

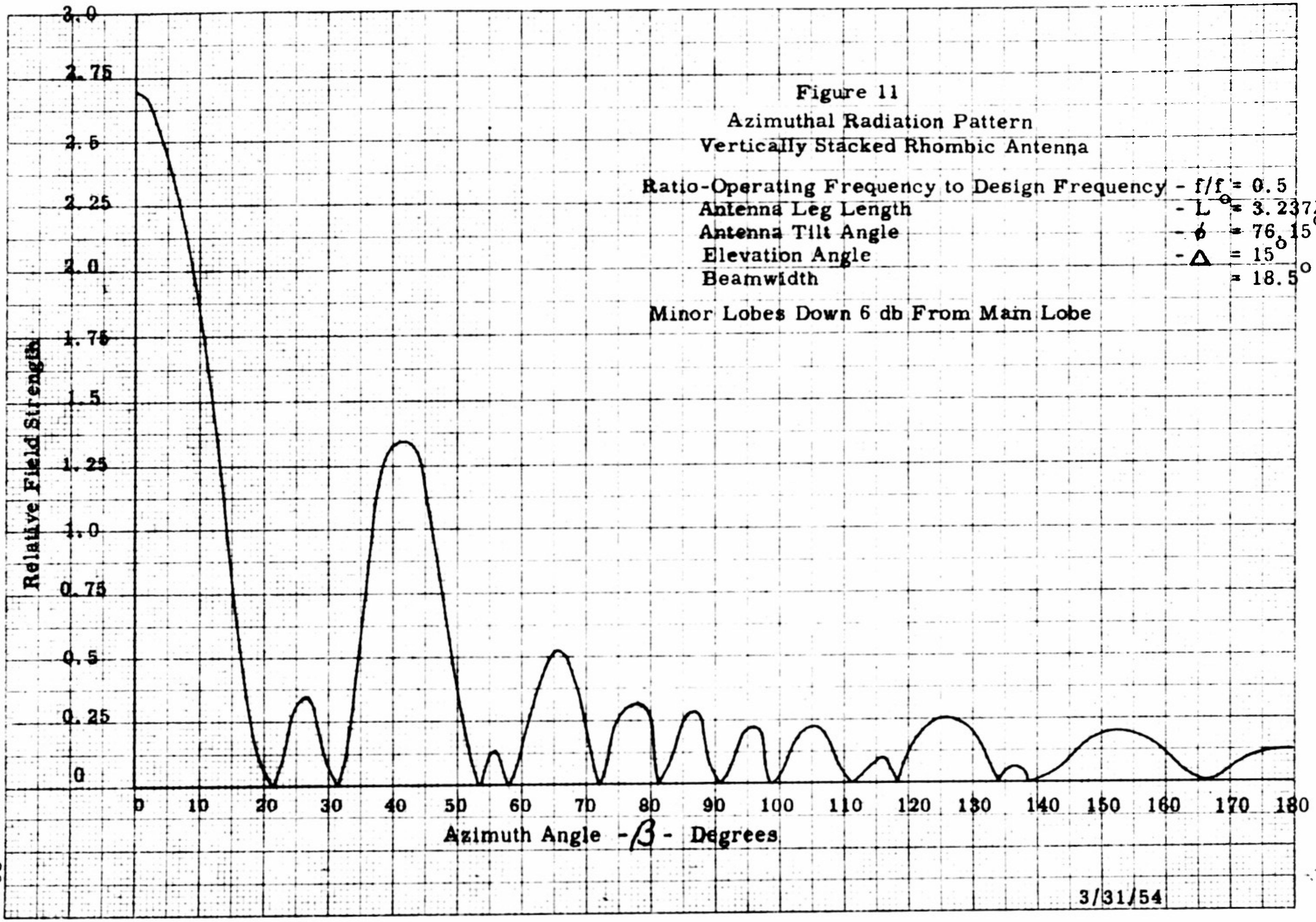


Figure 11
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna

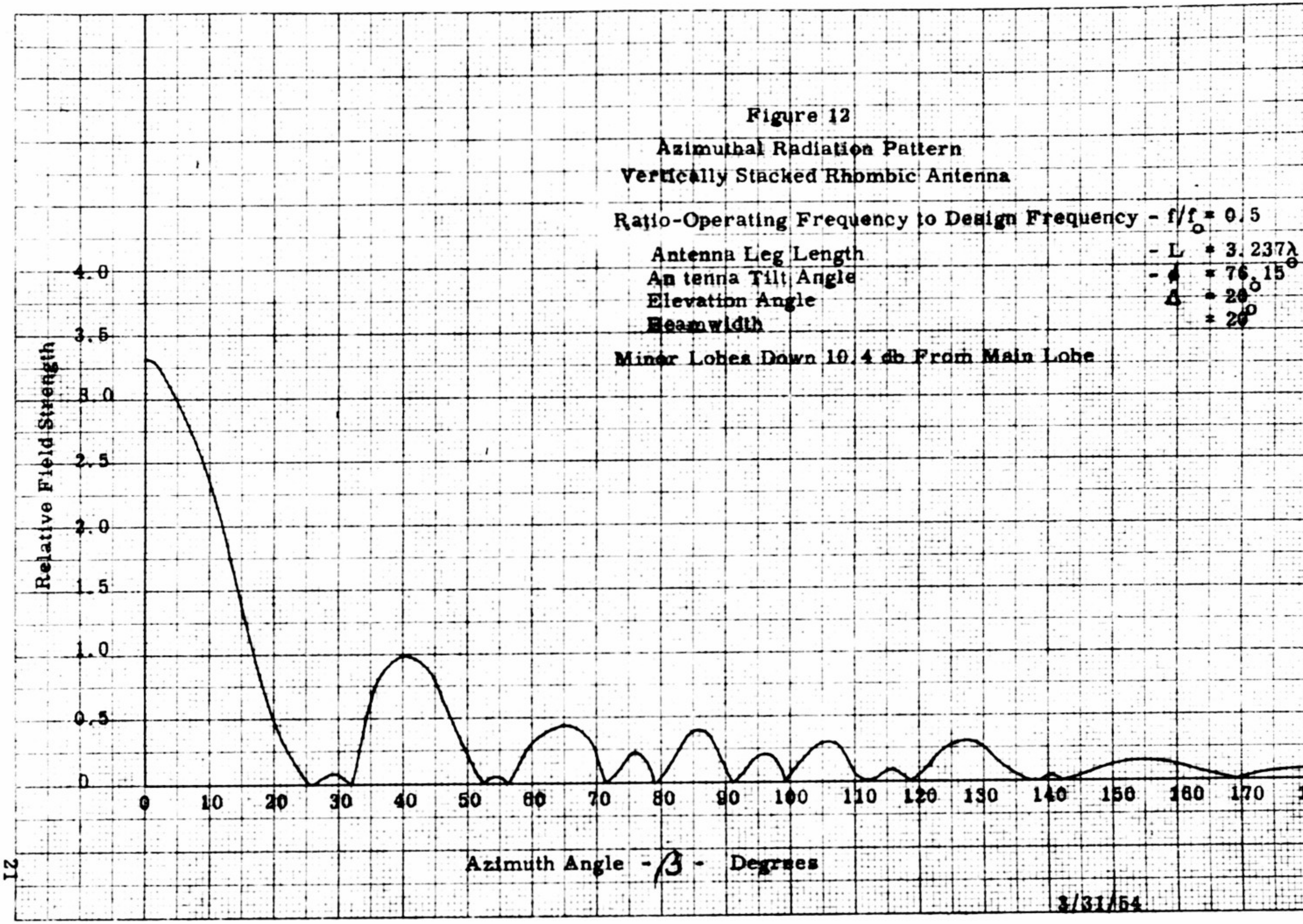


Figure 12

Azimuthal Radiation Pattern

Vertically Stacked Rhombic Antenna

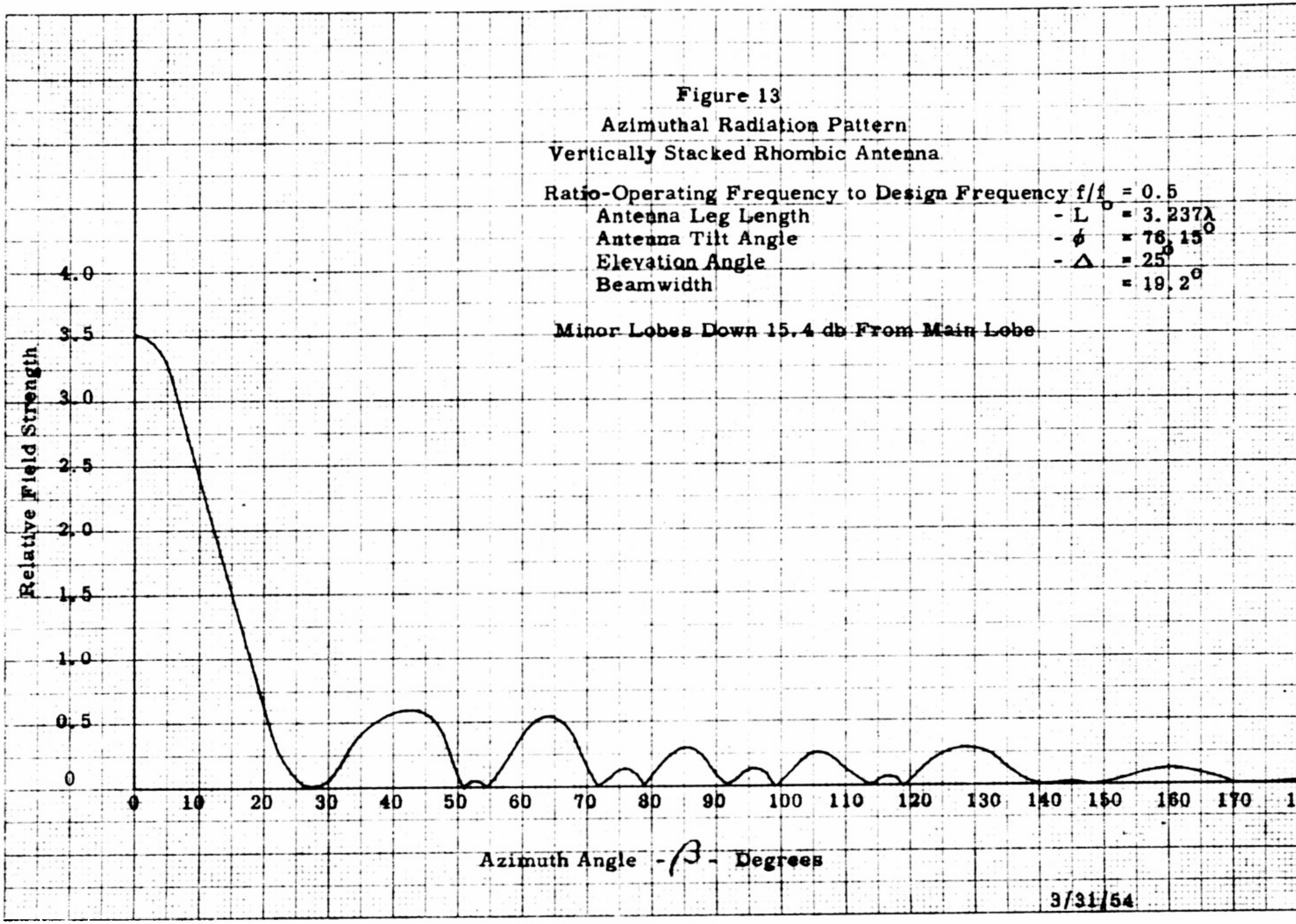


Figure 13

Azimuthal Radiation Pattern

Vertically Stacked Rhombic Antenna

Ratio-Operating Frequency to Design Frequency	f/f_o	= 0.5
Antenna Leg Length	- L	= 3.237λ
Antenna Tilt Angle	- ϕ	= 78.15°
Elevation Angle	- Δ	= 25°
Beamwidth		= 19.2°

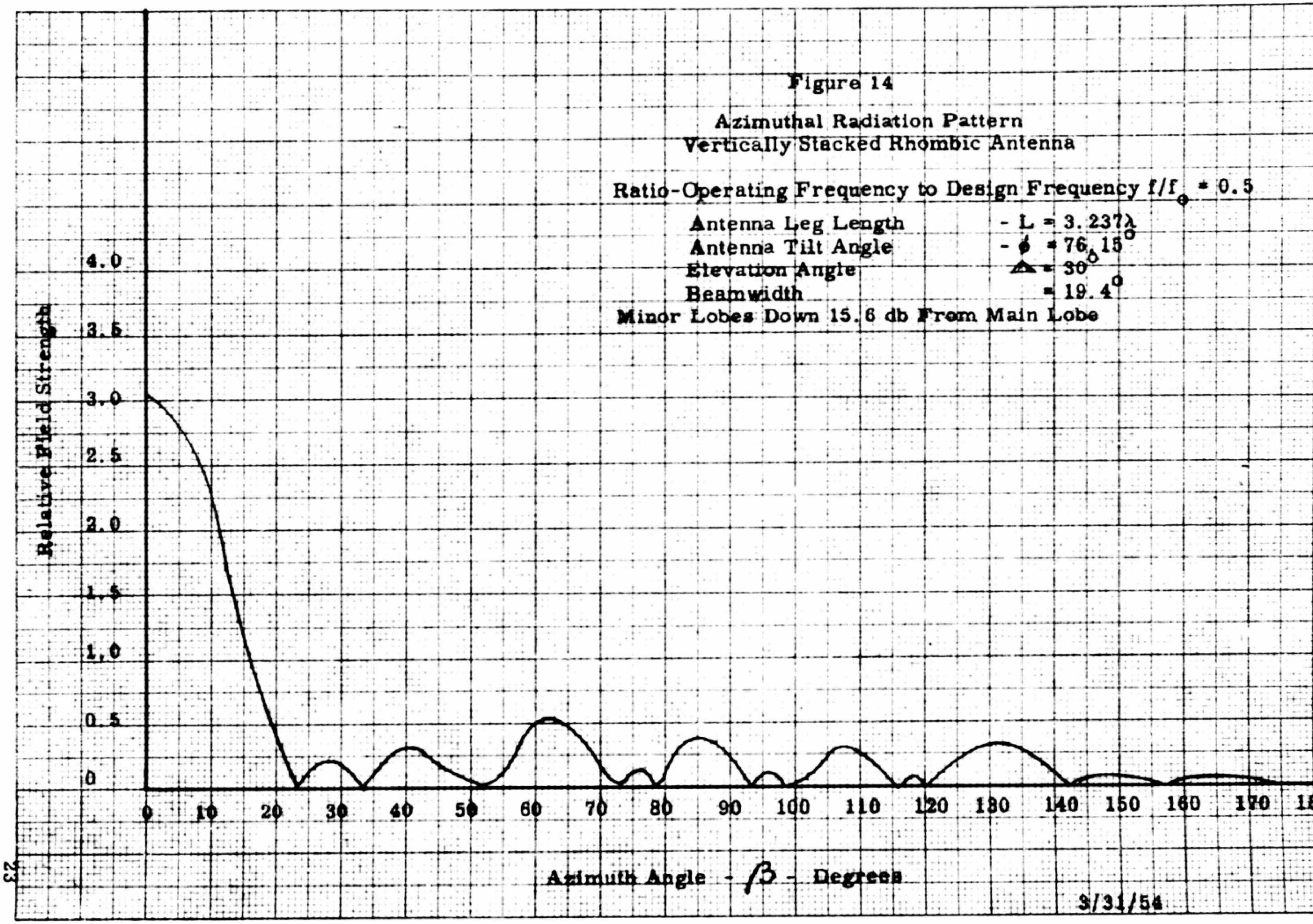


Figure 14
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna
Ratio-Operating Frequency to Design Frequency f/f0 = 0.5
Antenna Leg Length - L = 3.237λ
Antenna Tilt Angle - φ = 76.15°
Elevation Angle Δ = 30°
Beamwidth = 19.4°
Minor Lobes Down 15.6 db From Main Lobe
Relative Field Strength
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Azimuth Angle - β - Degrees
3/31/54

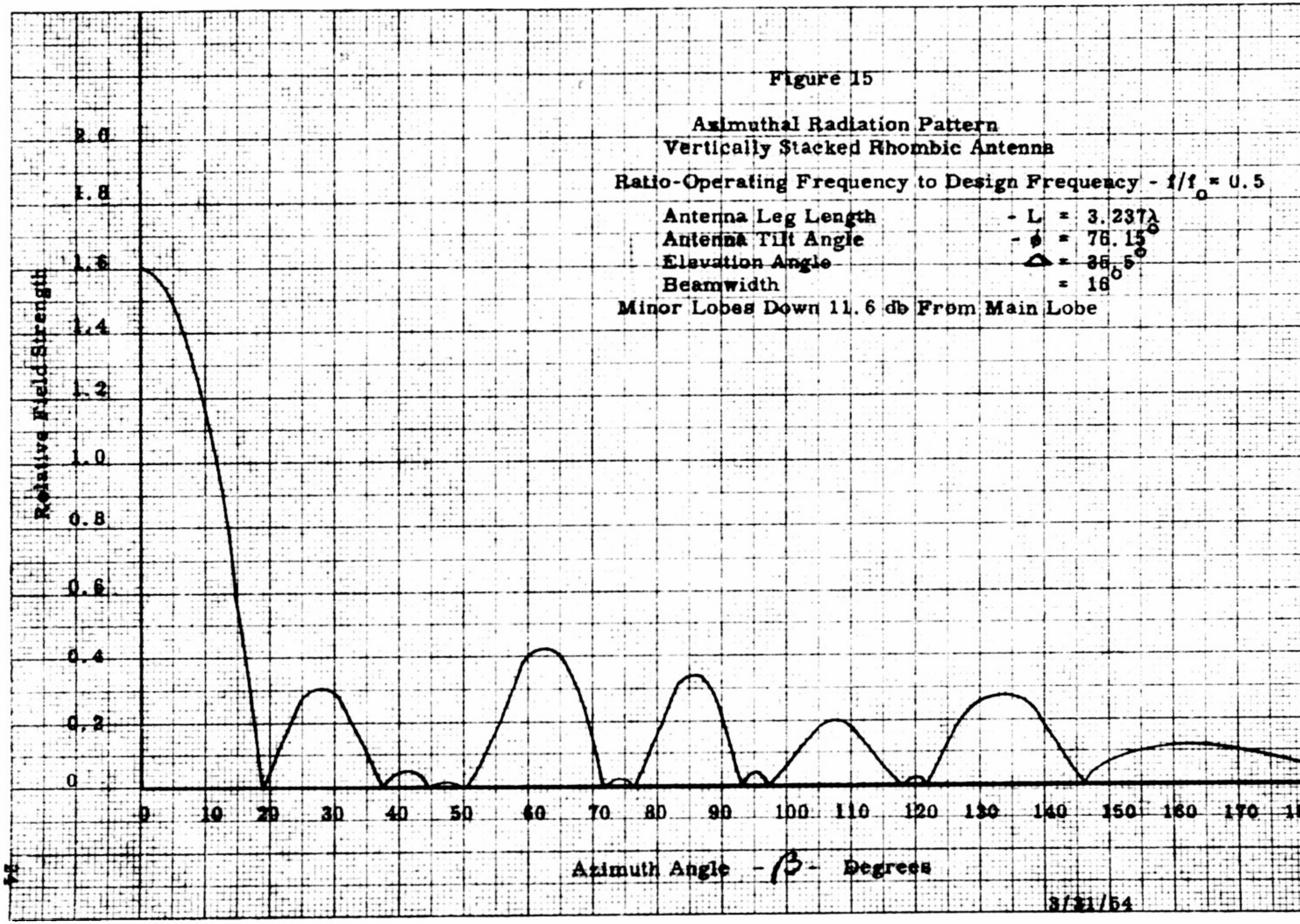


Figure 15
Azimuthal Radiation Pattern
Vertically Stacked Rhombic Antenna
Ratio-Operating Frequency to Design Frequency - f/f_o = 0.5
Antenna Leg Length - L = 3.237λ
Antenna Tilt Angle - ϕ = 76.15°
Elevation Angle Δ = 36.5°
Beamwidth = 16°
Minor Lobes Down 11.6 db From Main Lobe
Relative Field Strength
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Azimuth Angle - β - Degrees
3/31/54